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14. ABSTRACT

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Final report on

Fundamental studies on Light Strings: Equipment Upgrade

F49620-02-1-0248

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Contents

Abstract

The purpose of the equipment upgrade to our high peak power laser system was to enables us to produce "light strings" or "filaments" at 746 nm and 248 nm. The task of ordering the components, rebuilding the source and accessories has taken over a year. The adaptive optics system developed by Intellite did not provide us with an improved beam quality for filamentation. We have therefore opted for vacuum spatial filtering that has just been implemented. The ongoing tests and the theory led us to the realization that a high energy (2 J/pulse) solid state source, providing a better beam quality and pulse duration in the range of 200 ps to 2 ns, launched through an aerodynamic window, should create ideal filaments over long propagation distance. Two aerodynamic windows were successfully developed. Because of the operating costs of the system (the aerodynamic window requires a compressor rental for $3,500/month), a series of major tests have been postponed until March 1st, 2004, when all equipment — including the solid state source — is in place.

1 Background

A call for proposal on adaptive optics techniques from the Air Force started with the statement: "Since atmospheric effects impose a fundamental limitation on the propagation of light in air,...". Such a statement is only correct as it applies to linear propagation of light in air. Even air is a nonlinear optical medium for sufficiently high intensities. The index of refraction of air has a dependence on the beam intensity I, which, to first order, is $\bar{n}_2 I = n_2 \mathcal{E}^2$, where $\mathcal{E}$ and I are respectively the electric field amplitude and the intensity of the radiation. In the visible, n_2 is a positive number, hence the nonlinear index leads to self-focusing. Once the beam power is sufficient for self-focusing to overcome diffraction, the beam collapses to a point. In general, after the beam has collapsed, it diffracts. However, numerous experiments have shown self-guiding of high peak power femtosecond pulses through the atmosphere [1, 2, 3, 4, 5, 6, 7]. All but the second report [2], which involved fs pulses at 248 nm, were carried out in the near infrared. After reaching the focus, the light appeared to traps itself in self-induced waveguides or "filaments" of the order of 100 μm diameter. We have since our first report of 1995 [2] made experimental studies on UV filaments [8, 9, 10, 11, 12, 13, 14], developed a new plasma diagnostic technique to study the electron distribution [15, 16], studied the multiphoton ionization process associated with these filaments [17] and their application to laser induced discharge [18]. Our experimental work has led to a theoretical study [19, 14] indicating that more energetic filaments could be obtained with longer pulses of the same peak power. Having a larger reservoir of energy compared to a steady stream of loss to three photon ionization, these filaments should propagate much further. Tests be made with a quadrupled Nd:YAG laser, compressed by Brillouin stimulated scattering to 200 ps, providing 2 J pulses at 266 nm. The length of filaments propagating at 248 nm and 266 nm is expected to be ultimately limited by Raleigh scattering. A solid laser based on Ce:LiCAF source at 290 nm does not have this limitation, and in addition will provide us the flexibility to operate between a few ps and 200 ps pulse duration.

2 Present Status: difficulties to match theory and experiments

Despite a very large number of publications on the topic of IR filaments, it is fair to state that the phenomena involved are not even qualitatively understood. More relevant than the *published* literature is the extensive

reviewer controversy associated with most papers, resulting in an exchange of correspondence that sometimes dwarfs the paper under scrutiny (which gets ultimately published without the critique). We present first an overview of the main experimental and theoretical difficulties associated with this problem. There is hope that these difficulties will be overcome in the coming years, thanks to the equipment that has been acquired through the AFOSR equipment grant. The benefit from mastering the filament production and stability through the use of aerodynamic windows and longer, more energetic UV pulses are quite impressive. What one hopes to achieve is:

- Transmission without diffraction: possibility to channel high energies in 100 μm channels
- Channels that are not affected by turbulence (small scale)
- Use of the backscattered radiation to provide a point source for adaptive optics correction (beam pointing of the filament) and for spectroscopy of the traversed atmosphere

2.1 Experimental difficulties

One of the main technical difficulty associated with the study of filaments is that air is one of the medium with the lowest non-linearity. Therefore, any optical component put in the path of the filament will have a larger influence on the filamented field that air. The nonlinear index of glass for instance is two orders of magnitude larger than that of air. The best technique to date to attenuate a high intensity beam is to reflect most of the intensity on a pure dielectric at grazing incidence. In the case of a filament of 100 μm diameter, the peak intensity is generally large enough to induce nonlinear absorption at the surface. The fraction of the beam transmitted has generally still sufficient intensity to be phase modulated by transmission through the glass. This technique of sampling the beam with a grazing incidence plate can however be applied to measure dramatic nonlinear effects in the formation phase of filaments, as shown in ref. [20].

Another solution that applies directly to filaments, and that we have just started to implement, is to use air as a window. The filament is sent through an aerodynamic window (a properly shaped supersonic nozzle) between atmosphere and vacuum. Once the filament is in vacuum, it will diffract, and expand to a size such that attenuating linear elements can be used without fear of inducing nonlinear interaction.

Air has also a very low index of refraction and dispersion, much lower than that of any transmissive optics used in diagnostics instrumentation. Therefore, the temporal structure of the filamented pulse will be modified (in general "washed out") by transmission through the windows, lenses *etc...* of the measuring device. In all measurements that we have presented, we have been careful to correct any temporal structure for the transfer function of all optical components preceding the detection.

A lot of confusion and difficulty in the interpretation of data arises from the dynamical interaction between the beam and filaments, and the fact that single shot measurements on single filaments are nearly impossible. A filament will disappear in less than one meter if isolated from the surrounding beam by an aperture [21]. Filaments have been observed to disappear and form within the beam [22]. Observation of filaments is often made either through the impact of the filament on a target, or through the conical emission. Impact of a filament on a target can be seen at distances up to 100 m, but this does not imply that a single filament can survive over that distance. Different filaments form and disappear over the length of 100 m. Similarly, return from conical emission from filaments has been observed over 13 km [6, 7]. This observation in no way implies that filaments exist over this distance. The conical emission from each filament has only a divergence of the order of 1 mradian, and an energy of the order of a fraction of mJ. There is sufficient illumination of the irradiated area at 13 m to allow for single photon detection of the backscattered radiation, even if individual filaments existed only over a distance of 10 meter.

Another fundamental problem in the measurement on filaments is the difficulty of defining an initial condition. The starting point of the filament is extremely dependent on the shape of the initial beam profile and wavefront, and on external perturbations such as air turbulence. To better define the experimental condition, many authors have used a converging geometry, in order to measure the length of a single filament [23, 22, 24]. These length measurements, based on fluorescence [23, 24], conductivity [22] and electromagnetic pulse detection [24] all indicated a filament length of the order of the meter, the same as we reported for the UV filaments [8]. It remains to be established whether this short length of filament is to be attributed to the decreasing power of the diverging main beam surrounding the filament, or to the initial (converging) condition for the filament, or whether this is the real intrinsic filament length.

One solution to the problem of creating a reproducible, controllable initial condition at a well defined position along the beam, is to focus the pulse in vacuum, and launch the waist into the atmosphere through an aerody-

namic window. Our efforts in this direction are detailed in Section 6.

3 Highlights — IR versus UV filaments

3.1 Some classic overstatements

Some misinterpretation of literature reports have led to erroneous statements. The main ones are:

- Filaments have been observed over 13 km
- A single filament has been measured over 100 m

The first overstatement results from the report that "White light (conical emission) generated by filaments has been backscattered from an altitude of 13 km." This fact in no way implies that the filaments were propagating to that altitude. The second confusion results from the fact that it has not been possible so far to make single shot measurements of filaments. The correct statement is that "The range over which filaments were observed was exceeding 100 m." As demonstrated by measurements with the "teramobile" reported by Mysyrowicz, and seen in numerical simulations of Kolesik [25], there is a dynamic interchange between the filaments and the surrounding beam: filaments disappear over a relatively short distance and are replaced by new ones. There is no continuity in the filament, which is important in applications such as guided discharges.

3.2 Data on IR filaments

Filaments is a very rich new field, with only very few data points compared with the huge array of parameters involved. Highlights from IR filaments at 800 nm are:

1. The teramobile shoots multiple filaments over several km (turbulent exchange of filaments within the beam diameter)
2. Startup of filamentation can be controlled by chirp.
3. Range gated white light detected over 13 km
4. Filaments are not affected by thermal turbulences

There has been a considerable amount of theoretical work, much less experiments. Despite the extensive theoretical modelling at 800 nm, it is fair

to state that a good understanding has not been reached. Recent measurements taken by my student Aaron Bernstein at Sandia Laboratories show the pre-filament evolution of the filament, before the beam has collapsed to a diameter such that all nonlinear effects have to be taken into account. Even though those measurements are the most accurate in the field, and are in condition considerable simpler than those of the filaments, no theory has yet been able to even qualitatively reproduce these measurements. The conditions are:

- Diameter of the beam between 4 and 1 mm
- Intensity far below that required for onset of ionization or conical emission
- The only effects to take into account are dispersion, rotational and vibrational Raman, the nonlinear index, and the "shock term".

Figure 1 shows just one example of such measurements. The autocorrelations taken for increasing initial pulse energy are plotted in false color (the color coding is indicated on the left. Some sample autocorrelations are shown on the left, and corresponding spectra on the right. As the initial energy increases, the pulse are seen to split temporally, and the spectrum broadens. In the spatial domain however, the beam reduces in diameter, but keeps a smooth beam profile, evolving gradually from Gaussian to "sub-Gaussian" (i.e. double sided exponential). No theory has been able to reproduce simultaneously the absence of spatial structure, together with a pulse splitting in time. The pulse peak intensity never reaches a value at which any ionization could be expected.

The nonlinear propagation — even prior to forming filaments — is extremely sensitive to parameter variation (in fact more sensitive than the accuracy of the available data). We contributed to the determination of one data point with the highest accuracy: the dispersion of air at 800 nm. With a Ti:sapphire laser mode-locked and stabilized to a reference cavity, we measure the dispersion of air at 780 nm to be 0.18 fs^2/cm, which places a data point with absolute accuracy in the plot of dispersion versus wavelength measured by Diddams in Boulder, Co, by white light interferometry [26]. The plot is reproduced below in Fig. 2. Coincidentally, the measurements at Boulder and UNM correspond to the same atmospheric conditions of 20°C, 640 torr, and 10% relative humidity.

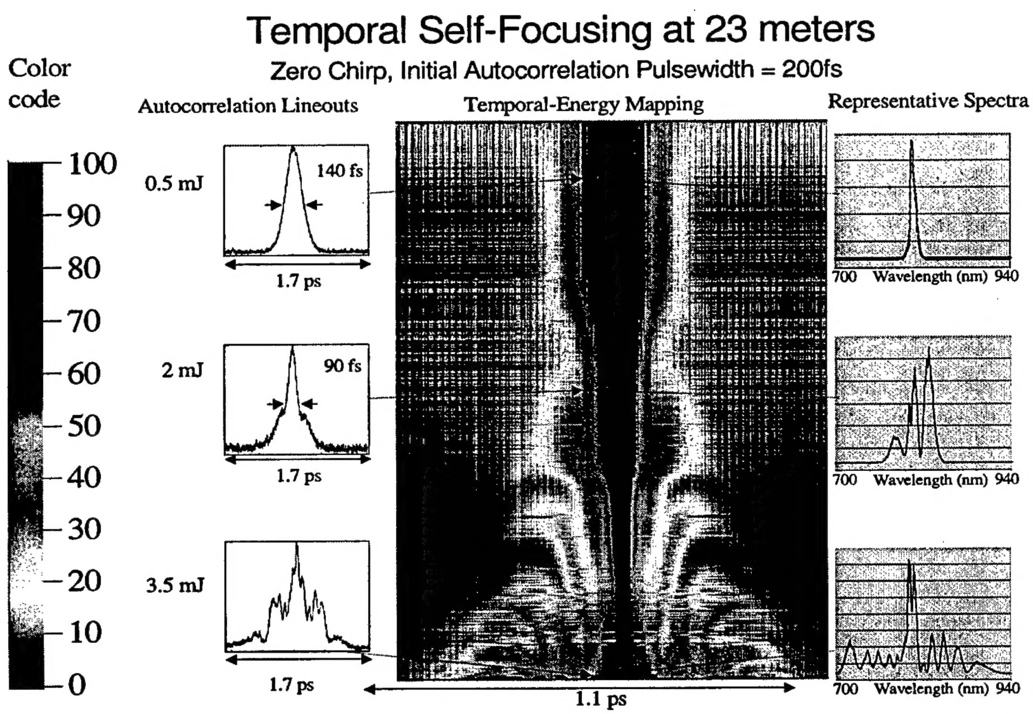


Figure 1: Autocorrelations versus initial pulse energy, at a distance of 23 m from the source.

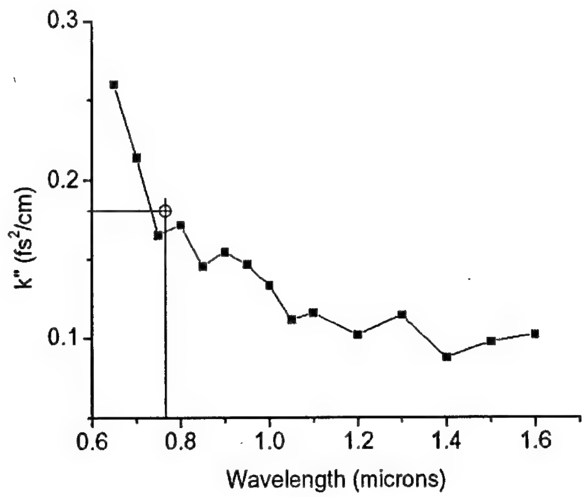


Figure 2: Plots of the dispersion of air as measured by white light interferometry. The data point at 780 nm is our group velocity measurement in a reference cavity, using a stabilized mode-locked Ti:sapphire laser [27].

3.3 Comparison of UV and IR filaments

Most studies are concentrated around mainly two wavelengths: 800 nm and 250 nm. There is considerable qualitative and quantitative differences between near IR and UV filaments.

	800 nm	250 nm
Pulse duration	< 200 fs	500 fs to 2 ps to 1 ns?
Energy/filament	6 to 10 mJ	0.2 mJ
Intensity	> 500 TW/cm^2	1 TW/cm^2
Conical Emission	About 50% of the energy	**none**
Energy loss/m	???	40 μJ/m

Table 1: Comparison between (known) characteristics of IR and UV filaments.

4 Summary of the results from UNM on UV filaments

A summary of the results of measurements made with UV filaments is presented in Fig. 3.

Measurements on UV filaments

Pulse duration	**1 ps**
Diameter	**100 μm**
Intensity	**1.4 TW/cm^2**
Energy loss/m	**40 μJ**
n_2	**7.8 10^{-19} cm^2/W**
Electron density N_e	**5 10^{15} cm^{-3}**
Ionization coeficient for oxygen:	
$\sigma^{(3)}$	**3. x 10^{-29} cm^6 s^2/J^3**

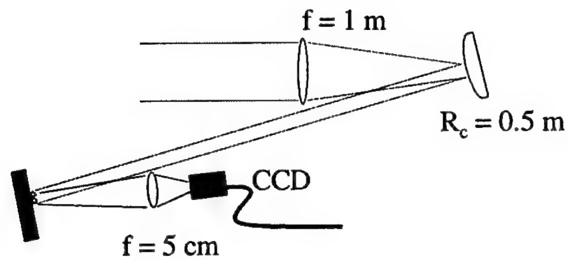
20 x more conductivity than IR filaments, for 100x less energy!

NO LOSS BY CONICAL EMISSION

Figure 3: Summary of the measurements on UV filaments

4.1 Measurements on the filament length

The tandem of excimer lasers used to generate a filamenting beam creates a highly distorted beam with poor pulse to pulse reproducibility. This is a fundamental problem associated with the high pressure discharge of the excimer amplifiers. We have however been able to collect a wealth of information on the filaments by studying the statistics of the impact of filaments on a target of steel. The experimental procedure is summarized by Fig. 4. These measurements have been correlated with other measurements of multiphoton ionization of air and plasma density (see below). The picture that emerged [8, 28, 10] can be summarized as follows:



2D and 3D picture of plasma plumes

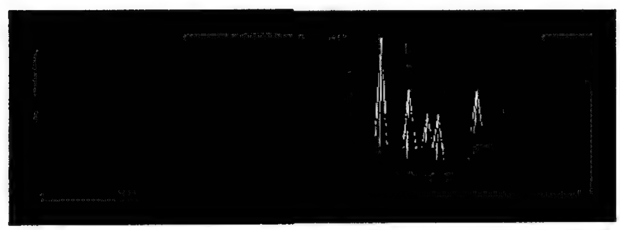


Figure 4: The impact of the filaments (at 10 Hz) is recorded on a CCD camera. From this "movie", we are able to extract a statistical analysis of the distribution of filaments as a function of various parameters (distance, energy, etc...).

Pulse duration	1 ps
Filament diameter	100 μm
Intensity on axis	1.4 TW/cm^2
Energy loss per meter	40 μJ
Electron density on axis	$5 \cdot 10^{15}$
Ionization coefficient (O)	$3\ 10^{-29}$ cm^6 s^2/J^3

The most important result from the experimental study is that filaments made with different pulse duration, in the range of 500 fs to 2 ps, has the same intensity. This is expected if the filaments result from balance between self-focusing (n_2I) and self-defocusing due to the photoelectron (three photon ionization of oxygen) plasma. The implication is that much more energetic filaments could be generated in the UV, using longer pulses. These filaments would propagate over distances of several km, as shown in the section 5.

4.2 Absence of conical emission in the UV

Measurements at 800 nm by my student Aaron Bernstein indicate that the energy lost to conical emission is a significant (more than 10%) fraction of the energy contained in a single filament. In the UV, we have established [8] that there is no such conical emission, because of the much lower intensity in these filaments. Another group had reported a measurement of conical emission in the UV. We have established that the broadened spectrum measured by the French group was in fact the change in spontaneous emission from the excimer laser, with or without a seed pulse. This measurement is reproduced in Fig. 5. The upper part of the figure shows that a broader spectrum (squares) is recorded when a seed pulse is sent through two excimer amplifiers (condition leading to filamentation) as compared to the spectrum (circles) when the seed pulse is sent through only one amplifier, hence too low amplification to lead to the creation of filaments. The lower part of the figure proves that the broadened radiation originates in the excimer laser rather than in the filament A pair of gratings is used to filter the radiation from the source *before* the beam is reduced in size to lead to the formation of filaments. It is seen that over four decades, there is no measurable conical emission.

4.3 Conductivity and Laser Induced discharge

The question of how much ionization is produced in a filament illustrates well the difficulty in matching theory and measurements with filaments. We used a variety of techniques to measure the three and four-photon ionization coefficients of oxygen and nitrogen that are responsible for the creation of the photo-electron plasma generated in the UV filament. The results and these techniques are described in ref [17]. The results of direct measurements of the ionization coefficient of air at 248 nm, in a vacuum cell, with the amplified excimer laser is 2 $10^{-30}\text{cm}^6\text{s}^2/\text{J3}$, to be contrasted with the value 3 10^{-29} cm^6 s^2/J^3 deduced from our measurements on filaments. The one order of magnitude difference is quite within the error bar of the direct measurement. The poor quality of the excimer laser beam makes the determination of the focal volume in which the ionization takes place very inaccurate. However, with that lower ionization coefficient value, filaments could not even exist in the condition in which they are observed. The combination of filament diameter, energy, energy loss/meter, established a much more accurate lower limit on the ionization coefficient.

The same difficulty has been seen in the literature with filaments at

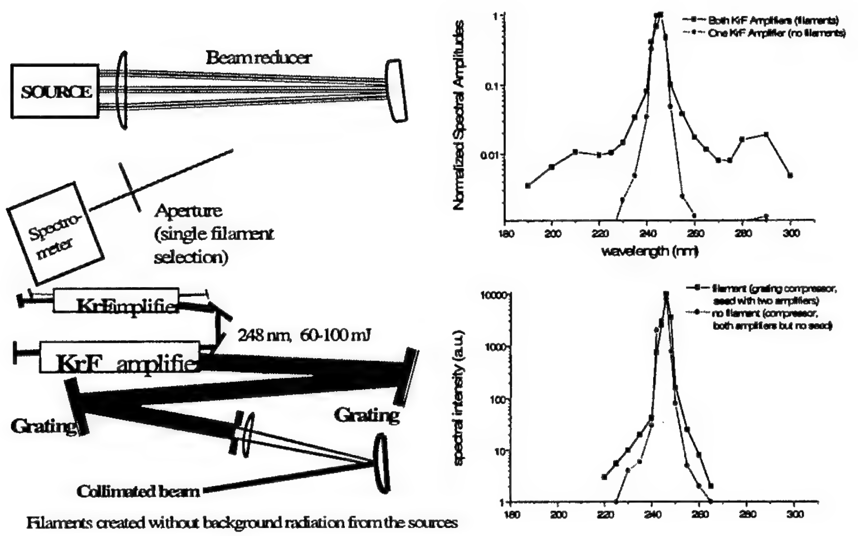


Figure 5: Top: False conical emission as measured without filtering the radiation from the source. The depletion of the excimer amplifying media through the amplified pulse results in a modification of the background emission. Bottom: a pair of gratings is used after the excimer amplifiers to spectrally filter the pulse prior to the formation of filaments. The observed spectrum is the same with or without the formation of filaments.

800 nm. Direct measurements of the conductivity by the filaments led to values ranging from $10^{12}\mathrm{e}^-/\mathrm{cm}^3$ [29] to $10^{16}\mathrm{e}^-/\mathrm{cm}^3$ [30]. Our comparative measurements of UV and IR filaments established that only the lower value is possible, since UV filaments created a 20 times higher conductivity than the two orders of magnitude more intense IR filaments. This value is quite accurate: a higher value of ionization coefficient at 800 nm would imply that the UV filaments would create more electrons than the ratio of pulse energy to ionization coefficient!

The filaments are potentially a means of inducing electrical discharges in the atmosphere over long distances. We have published an extensive study of this problem [18]. Efficient ionization is not a sufficient condition for creating a discharge. The electron plasma created in subpicosecond times will evolve. A new method of plasma interferometry enabled us to determine that the electron recombine after approximately 200 ps, to be replaced by an expansion shock wave which could induce a discharge over a distance of only 1 meter. Creating a long high voltage discharge channel of several meters could be achieved if a second laser is sent simultaneously with the UV

filament, of sufficient energy and duration to heat the plasma and prevent electron attachment to oxygen, for the time interval it takes to establish a discharge.

Plasma diagnostics A new method of plasma interferometry was developed to study the time evolution of the photo-electron plasma. This study has been published in Optics Communication [16]. The basic idea is to use the Mach Zehnder interferometer that splits an ultrashort pulses in a two-pulse sequence as the analyzing spectrometer for spectral interferometry.

5 Scaling filaments to longer duration

The experimental evidence collected so far on UV filaments indicates that the intensity in the filament is the main parameter that determines their cross section, as resulting from a balance between self-focusing and plasma defocusing. Therefore, they might be scalable to longer duration, hence higher energy, and able to propagate over longer distance. We developed a simple analytical model, that established limits of pulse duration (ns) and range (2 km) for such filaments [11, 19, 12, 13, 14].

The basic reason that UV filaments can be scaled to higher energy/duration is that inverse Bremstrahlung leads to avalanche breakdown in a very short (< 1 ps) with IR filaments. The time required to reach avalanche breakdown scales as $I \times \lambda^2$ [31]. With the weaker intensity filaments in the UV, this time has been calculated to be approximately 1 ns, allowing for the storage of 1 J into a filament.

For pulses longer than 200 ps, the ionization and recombination reach a steady state, which has led us to the analytical theory of filamentation in the UV. For the wavelength range from 248 nm to 306 nm for which the oxygen ionization is a three photon process, we can express the nonlinear index of refraction of air as:

$$n = n_0 + \tilde{n}_2 I - |\tilde{n}_{3/2}| I^{3/2}, \tag{1}$$

where the last term is the contribution of the electron plasma to the index of refraction. The number of electrons is proportional to the third power of the intensity $I^{3/2}$. Making a gaussian beam approximation within the paraxial approximation ($Ea = \mathcal{E}_0 \exp -r^2/w^2$, and substituting Eq. (1) into the wave equation, leads to the following coupled equations for the power beam diameter w:

$$\frac{d^2 w}{dz^2} = -\frac{4}{k^2}\left(\frac{P}{P_{cr}} - 1\right)\frac{1}{w^3} + \frac{6\ell}{n_0}\beta_4 \frac{1}{w^4} P^{3/2} \tag{2}$$

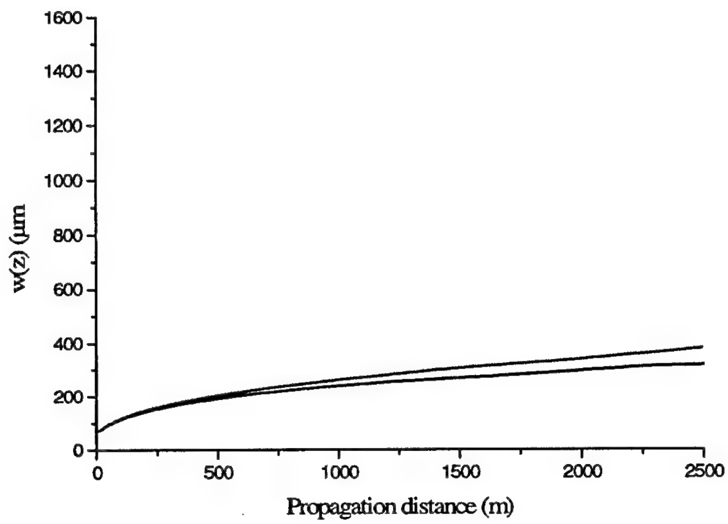


Figure 6: Filament size w versus distance, for an initial power 160 MW

and the power P:

$$\frac{dP}{dz} = -\left[\beta_3 \frac{1}{w^4} P^2 + \beta_4 \frac{1}{w^3} P^{1.5}\right] P \tag{3}$$

where we have introduced the critical power P_{cr}:

$$P_{cr} = \frac{\lambda^2}{8\pi n_0 \bar{n}_2}. \tag{4}$$

This critical power is 30 MW for air at atmospheric pressure, for 248 nm. Even though it applies only to the temporal range from 200 ps to 1 ns, the solution of the coupled system of equations (2, 3) exhibits a lot of features either observed experimentally or in the numerical simulations. For instance, the beam diameter w is seen to oscillate between a minimum and maximum value, as in the "dynamic replenishment" model of Moloney [32]. An example of solution of the coupled equations (Fig. 6) shows the envelope of the minima and maxima plotted as a function of distance. The corresponding plot of power versus distance shows a small initial drop for the first 50 meter (formation stage of the filament), followed by a constant power of 40 MW.

Another interesting result in agreement with experimental observations is that the energy losses occur in the formation stage. Figure 7 shows the

self-focusing and subsequent filamentation of an initial beam of 1 cm. As in the experimental observations, the beam power has to exceed the filamented power by at least two orders of magnitude, in order to create a filament. Here again, the solution to this problem is to focus the beam in vacuum to the ideal diameter, and launch the filament through an aerodynamic window, as discussed in the next section.

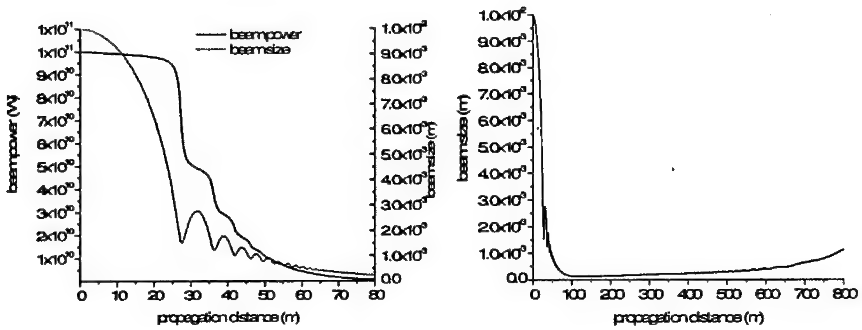


Figure 7: Filament size w and power P versus distance, for an initial waist of 1 cm, and an initial power of 11^{11} W.

Some results of the calculations performed on the "quasi state" filaments that are pertinent to the new series of experiments, are:

1. The propagation distance of the filament depends on the initial size of the filament, for a given initial power
2. The longest filaments are created with an initial beam diameter close to the filament diameter
3. For a given three photon ionization coefficient, there is a maximum length of filament as a function of initial power. It is a sharply peaked function.
4. The optimum power that creates the longest filament is a decreasing function of the ionization coefficient
5. The variations in filament diameter can be minimized by a proper choice of the initial beam diameter and initial power

6. Raleigh scattering limits the propagation length of the filaments. The longest filaments can be obtained at a wavelength around 300 nm.

All these results point out to the need to accurately control the initial beam profile, down to the size of the filament. Therefore, the importance of a improved spatial profile of the beam, through adaptive optics, larger size optics, spatial filtering, and aerodynamic window.

6 The aerodynamic window

Because most of the energy loss occurs in the formation stage (typically 100x more energy needed to make one filament than the energy contained in the filament), aerodynamic windows will enable us a much more efficient technique to launch filaments. The sensitivity of the formation stage to air turbulence is avoided by focusing the shaped beam and wavefront in vacuum. This should enable us to prepare arrays of filaments with pre-determined pattern, each filament carrying 1J of energy.

Figure 8 illustrate the concept of launching a filament through the window.

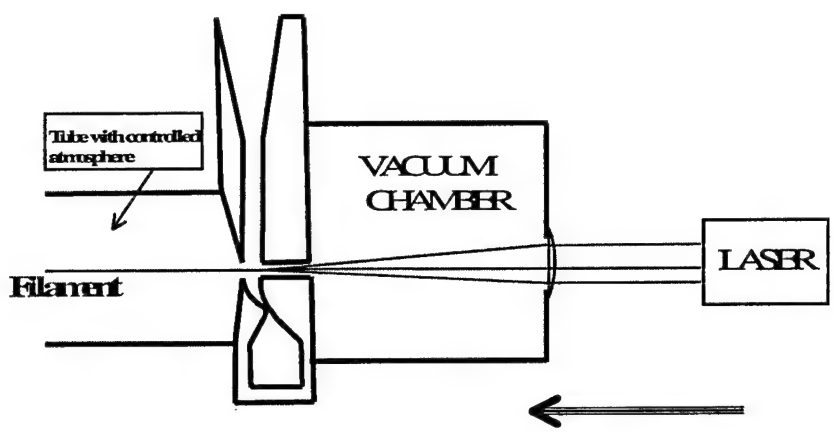


Figure 8: The beam is focused from its initial 4 cm diameter in vacuum, into the 3 mm aperture of the window.

A first aerodynamic was constructed with a 3 mm round aperture. A second one was made with vertical slit 2 mm $\times$ 15 mm to investigate the possibility to create predetermined patterns (linear arrays) of filaments.

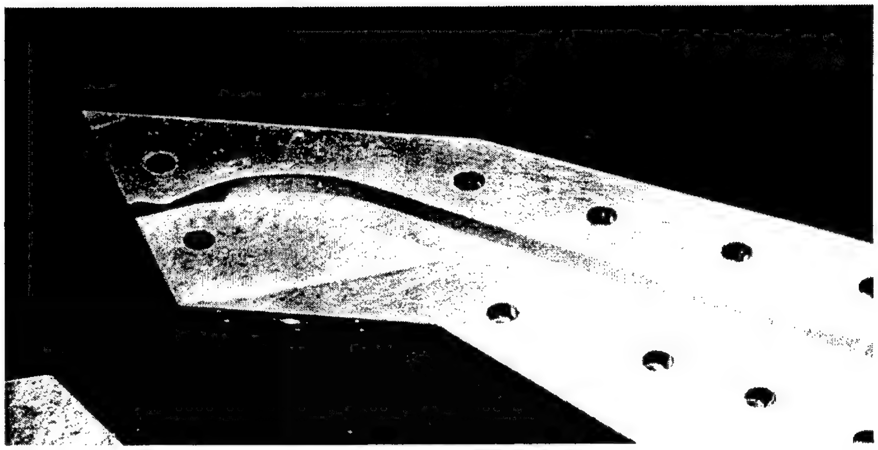


Figure 9: Photograph of the aerodynamic window disassembled, showing the narrow (2 mm) nozzle region, and the expansion chamber. The small hole at the top of the expansion chamber is at atmospheric pressure. The lower hole connects to the inside of the profile which is vacuum.

Another function of the aerodynamic window is for diagnostic purpose. As sketched in Fig. 10, the filament is launched from air into vacuum through the second window. The beam is let to diffract in vacuum, until reaching a sufficient size, such that the expanded beam can be linearly attenuated and analyzed with a CCD, spectrometer and autocorrelator. While the analysis is trivial in the case of an initial Gaussian beam profile, it becomes problematic with the beam from the excimer laser amplifier. Unless the filament is let to diffract in vacuum for more than 3 meter, the diffracted filament will interfere with the portion of the main beam sent through the aperture. A delicate balance has to be found between the size of the aperture, small enough so that the transmitted energy from the main beam be negligible, but large enough so that, at each shot, the filament passes through that hole.

Using compressed air cylinders, the aerodynamic window could only be operated for 50 seconds/cylinder. In view of the large parameter space to be investigated, the 50 s operation time is not sufficient to make a meaningful study. We have therefore arranged to rent a large compressor enabling continuous simultaneous operation of the two aerodynamic windows. A compressor of that size could only be installed at the other end of the Physics and Astronomy building, about 300 ft away from the laboratory. The electrical installation, plumbing of the compressor to two laboratories, have just

been completed. Tests of the filamentation with the excimer laser amplifier, as well as the fourth harmonic of Nd:YAG, are about to start.

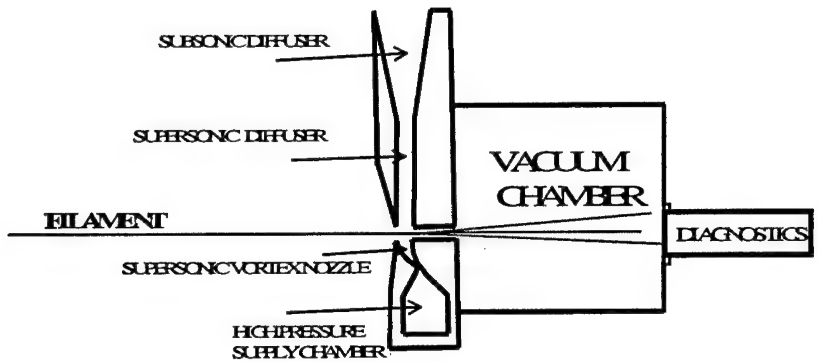


Figure 10: Sketch of the use of the aerodynamic window for diagnostic purpose. Once if vacuum, the 100 μm diameter will diffract. After a sufficient distance, the beam expanded to a size such that the intensity in the beam is low enough to use linear attenuators.

7 Developments on the fs UV source

The adaptive optics system purchased from Intellite failed to improve the quality of the amplified excimer beam. A spatial filter assembly ("Precision Applied Science") has been incorporated in the system. The regenerative amplifier, the three path amplifier, and the frequency tripler have been reconstructed with larger optics. We suffered an additional six month delay because of the failure of the Continuum (model Surelite II) pump laser. A new laser crystal, pockel cell, frequency doubler and optics had to be ordered.

8 New sources for long pulses

A quadrupled Nd:YAG laser a 266 nm, compressed to below 1 ns by stimulated backward Brillouin scattering, will be a first source to test the long duration filaments. Another option is to use a Ce:LICAF amplifier, pumped by a quadrupled Nd:YAG laser. The seed for the amplifier can be obtained

by nonlinear frequency conversion of a Nd:YAG Q-switched laser down to 290 nm, followed by Brillouin compression to 200 ps. The block diagram of the Ce:LICAF source is shown in Fig. 11.

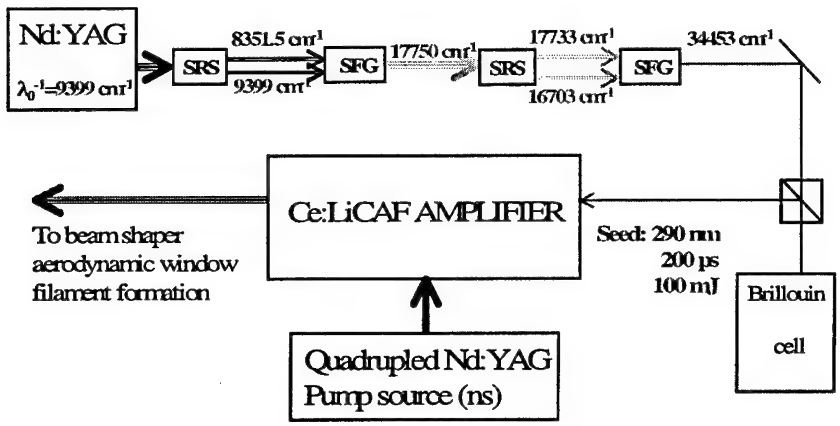


Figure 11: Block diagram of the solid state source at 290 nm in construction.

These sources provide clean Gaussian pulses, that can eventually be spatially shaped and focused in vacuum onto an air-vacuum interface, to generate a filament.

Filaments are known to form, disappear, coalesce, in a high power beam. The starting point is totally random. Since a single shot visualization of a filament is not possible, determining the length of a filament is next to impossible. With a single filament formed by an aerodynamic window, we have repeatable initial conditions for a single filament. It should therefore possible to make systematic studies of the filament length as a function of atmospheric composition, pressure, temperature, etc...

9 Conclusion

The theory and the preliminary experiments point to the following prospect that we hope to confirm with a series of tests using the aerodynamic window.

- The possibility to create an array of filaments, carrying 1 J of energy each, at 1 ¡ 300 nm

- To prevent the loss of energy and wavefront control: beam focalization will take place in vacuum, and the filaments will be launched through an aerodynamic window.
- Adaptive optics may still be required for active beam pointing control. The filament itself provides a remote guide star through the radiation emitted by the multiphoton excited ions
- For longest propagation distance of the filaments, the ideal wavelength should be 290 nm (Ce:LiCAF amplifier, no Raleigh scattering)

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